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## Studies on the Spatial Distribution Pattern of Soybean Aphid and Sampling Techniques

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**Abstract:** The results of our studies on the spatial distribution patterns of aphid populations and of the aphid infested plants in the field showed a spatial distribution pattern of aphids aggregated at certain density levels. Characteristics of aphid behavior, such as mutual attraction between individual aphids, were the cause for aggregation of soybean aphids. The basic elements of distribution are individual aphid colonies. The aphid infested soybean plants were either uniformly or randomly distributed when infestation rates were low, and uniform distribution prevailed as the infested rates increased to higher levels. Sampling methods such as parallel, chessboard and “Z” pattern sampling, were all applicable in the investigation of aphid population density. In addition, by referring to the linear regression equation between average crowdedness and mean proposed by Iwao and applying the  $\alpha$  and  $\beta$  values from the equation to the formulae of theoretical sampling numbers and sequential sampling, we may obtain the theoretical sampling numbers and results of sequential sampling for the investigation of both aphid density and the aphid infestation rate of soybean plants.

**Keywords:** Soybean aphid; average crowdedness; distribution pattern; sampling technique

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Soybean aphid (*Aphis glycines* Matsumura) is an important harmful pest in the soybean-growing regions in Northeast China. Aphid infestation occurs every year and causes different levels of yield losses in soybean production. In order to explore the dynamic pattern of aphid population, seek simple, easy, and labor and time save sampling method that can also reflect the actual aphid population and thus provide theoretical basis for investigation, prediction and control of soybean aphids, we conducted the field investigation and research work on the spatial distributions of aphid population with different population sizes and at different development stages, as well as the spatial distribution of aphid infested soybean plants in 1990.

### 1. EXPERIMENT METHOD

Our investigation was conducted in two fields planted only in soybeans under different ecological conditions chosen from the experimental fields of Shenyang Agricultural University. A square plot with two thousand soybean plants from each test field was used for the investigation. Starting on May 23 when soybean aphids began to infest soybean plants, aphid numbers on each plant were examined at an interval of two days. After June 5 and when the percentage of aphid infested plants reached 75%, aphid numbers were checked every 3 to 7 days. The number of examined soybean plants was 200. The examination was stopped when the aphid infestation rate reached 100% and aphid numbers per 100 plants were over 15,000. After each examination, the numbers of aphid infested plants and their aphid numbers were recorded in details and all the data about each infested plant were also marked on a plotting paper as their

position in the field. Every five or 10 plants was considered a quadrat (sampling unit) and data from each examination were considered a set. Then we statistically calculated the aphid number and infested plant number for each quadrat, infested rate as well as aphid density, mean number of infested plants ( $\bar{X}$ ) and variance ( $S^2$ ) for each set S. Dispersion parameters and other relevant methods were used to determine their patterns of spatial distribution and to study the techniques of sampling.

## 2. RESULTS AND ANALYSES

### 2.1 Patterns of spatial distribution

*2.1.1 Determination of the spatial distribution pattern of aphid population.* Every five or ten plants were considered as a quadrat. Data of each examination at a different time from both test soybean plots were treated as a set and used to calculate the set mean ( $\bar{X}$ ) and variance ( $S^2$ ).

Dispersion parameters, such as  $k$  [ $k = \bar{X}^2 / (S^2 - \bar{X})$ ],  $I$  ( $I = S^2 / \bar{X} - 1$ ),  $Ca$  ( $Ca = 1/k$ ),  $M$  (average crowdedness =  $\bar{X} + S^2 \sqrt{\bar{X}} - 1$ ), and  $M^* / \bar{X}$ , were used to determine the spatial distribution pattern. Results are shown in Table 1 and Table 2.

Table 1. Dispersion parameters of soybean aphid population (quadrat: 5 plants)

Field	Examined date	Aphid No. mean ( $\bar{X}$ )	Variance ( $s^2$ )	Parameters of dispersion					Aphid infested plants (%)
				k	J	Ca	$M^*$	$M^* / \bar{X}$	
I	05-23	4.36	35.89	0.60	7.23	1.66	11.59	2.66	21.00
	05-24	4.23	54.62	0.35	11.92	2.82	16.15	3.82	16.70
	05-26	7.42	156.63	0.37	20.12	2.71	27.54	3.71	21.90
	05-28	20.06	558.00	0.75	26.81	1.34	46.88	2.34	35.05
	05-30	32.09	1416.86	0.74	43.16	1.34	75.24	2.34	42.15
	06-01	35.15	1711.56	0.74	47.69	1.36	82.84	2.36	47.00
	06-03	73.86	6171.41	0.89	82.55	1.12	156.42	2.12	66.00
	06-05	144.87	22554.72	0.94	154.69	1.07	299.56	2.07	82.55
	06-10	444.30	254416.80	0.78	571.62	1.29	1015.92	2.29	100.00
	06-13	718.73	373755.00	1.38	519.03	0.72	1237.75	1.72	100.00
	06-18	1761.20	632662.30	4.92	358.22	0.20	2119.42	1.20	100.00
	06-25	1764.68	913003.50	3.42	516.38	0.29	2281.05	1.29	100.00
II	05-24	2.13	14.55	0.36	5.85	2.75	7.97	3.75	12.00
	05-26	5.02	65.89	0.41	12.14	2.42	17.15	3.42	19.30
	05-28	11.62	187.66	0.69	16.03	1.46	27.05	2.46	29.25
	05-30	18.93	559.01	0.66	28.54	1.51	47.46	2.51	35.75
	06-01	23.18	908.72	0.61	38.21	1.65	61.39	2.65	42.20
	06-03	44.81	2601.93	0.79	57.06	1.27	101.88	2.27	50.15
	06-05	99.83	18669.02	0.54	186.00	1.86	258.84	2.86	78.00
	06-10	201.65	60469.14	0.67	298.87	1.48	500.52	2.48	100.00
	06-13	545.80	228648.80	1.31	417.92	0.77	963.72	1.77	100.00
	06-18	989.68	816315.50	1.20	823.83	0.83	1813.51	1.83	100.00
	06-25	784.73	637686.10	0.97	811.62	1.03	1596.35	2.03	100.00

Table 1 and Table 2 listed the 46 sets of data from test plot I and II with 5 or 10 plants as a quadrat. Data in both tables indicated that the spatial distribution of aphid population was a

contiguous distribution because their dispersion parameters had the characteristic values of  $k < 8$ ,  $I > 0$ ,  $Ca > 0$ , and  $M/\bar{X} > 1$ . The data set in Table 2 obtained on June 10 [June 18] was an exception, which had a value of  $k > 8$  and showed the characteristic of random distribution. All the  $M$  values were above zero, which also indicated the presence of individual colonies. All these data revealed that the spatial distribution of aphid population was aggregated from the initial aphid infestation to the peak outbreak stage, or from the infested plant rate of 12% to 100% regardless of the density of aphid population and the dispersion situation.

We also applied the regression equation between average crowdedness ( $M$ ) and mean ( $\bar{X}$ ) reported by Iwao (1971, 1972), and the regression equation between variance ( $S^2$ ) and the log value of mean ( $\bar{X}$ ) proposed by Taylor (1961, 1965, 1976) to examine the distribution pattern. Statistical results of the 23 sets of data from both test plots were:

$$\begin{aligned} M &= \alpha + \beta \bar{X} = 97.44 + 1.36 \bar{X} \text{ (5 plants)} & r &= 0.97 \\ M &= 99.29 + 1.23 \bar{X} \text{ (10 plants)} & r &= 0.99 \\ \log S^2 &= a + b \log \bar{X} = 0.59 + 1.73 \log \bar{X} \text{ (5 plants)} & r &= 0.995 \\ \log S^2 &= 0.37 + 1.75 \log \bar{X} \text{ (10 plants)} & r &= 0.996 \end{aligned}$$

Table 2. Dispersion parameters of soybean aphid population (quadrat: 10 plants)

Field	Examined date	Aphid No. mean ( $\bar{X}$ )	Variance ( $s^2$ )	Dispersion parameters					Aphid infested plants (%)
				k	j	Ca	$M$	$M/\bar{X}$	
I	05-23	8.72	72.94	1.19	7.36	0.84	16.08	1.84	21.00
	05-24	8.46	108.42	0.72	11.82	1.39	20.28	2.39	16.70
	05-26	14.83	340.21	0.68	21.94	1.48	36.77	2.48	21.90
	05-28	40.13	1156.83	1.44	27.83	0.69	67.96	1.69	35.05
	05-30	64.18	2861.38	1.47	43.59	0.68	107.67	1.68	42.15
	06-01	70.30	3892.76	1.29	54.38	0.77	124.67	1.77	47.00
	06-03	147.73	15572.49	1.41	104.42	0.71	252.14	1.71	66.00
	06-05	289.75	57772.84	1.46	198.39	0.68	488.14	1.68	82.55
	06-10	888.60	537324.50	1.47	603.69	0.68	1492.29	1.68	100.00
	06-13	1437.45	778291.40	2.66	540.44	0.38	1977.89	1.38	100.00
	06-18	3522.40	1481649.00	8.39	419.64	0.12	3942.04	1.12	100.00
	06-25	3529.35	2844782.00	4.38	805.04	0.23	4334.39	1.23	100.00
II	05-24	4.25	31.67	0.66	6.45	1.52	10.70	2.52	12.00
	05-26	10.03	138.41	0.78	12.80	1.28	22.83	2.28	19.30
	05-28	22.04	381.58	1.35	16.32	0.74	38.35	1.74	29.25
	05-30	37.85	1148.58	1.29	29.35	0.78	67.20	1.78	35.75
	06-01	46.35	1970.99	1.12	41.52	0.90	87.87	1.90	42.20
	06-03	89.63	6655.75	1.22	73.26	0.82	162.89	1.82	50.15
	06-05	199.67	41223.17	0.97	205.46	1.03	405.13	2.03	78.00
	06-10	403.30	135807.80	1.18	342.44	0.85	745.74	1.85	100.00
	06-13	1091.60	459869.20	2.59	420.28	1.39	1511.88	1.39	100.00
	06-18	1979.35	2207924.00	1.78	1114.48	0.56	3096.83	1.56	100.00
	06-25	1569.45	1171778.00	2.10	745.62	0.48	2315.07	1.48	100.00

The above results showed that all the equations had parameter values of  $\alpha > 0$ ,  $\beta > 1$ , and  $b > 1$ , which still indicated the spatial distribution of aphid population was a contiguous distribution under all the density levels. The intensity of aggregation increased as the density of aphid population increased. It also indicated that aphids were attracted to each other, and the basic elements of distribution were individual colonies.

The aggregation mean ( $\lambda$ ) could be used to differentiate if the aggregation of aphid population was caused by the behavior of the aphids or by environmental conditions.

$$(\lambda) = \frac{\bar{X}}{2k} \bullet r$$

Where  $r$  is the function of  $X^2$  with a freedom of  $2k$ , i.e. the  $X^2$  value in the distribution table of  $r = X^2$  when the freedom is  $2k$  and the probability is 0.5. The results of calculation showed that all the ( $\lambda$ ) values were  $> 2$  except the value from the data on May 24 in plot II, which also indicated that the aggregation of soybean aphids was the result of their own behavior.

*2.1.2 Measurement of the spatial distribution pattern of aphid infested plants.* The spatial distribution pattern of aphid infested plants was determined by the dispersion parameters based on 14 sets of data collected before June 10 from both test plots I and II with 5 plants as a quadrat. Results are shown in Table 3.

Table 3. Dispersion parameters of soybean aphid infested plants (quadrat: 5 plants)

Field	Examined date	Aphid mean ( $\bar{X}$ )	Variance ( $s^2$ )	Dispersion parameters				Aphid infested plants (%)
				j	Ca	$\overset{*}{M}$	$\overset{*}{M}/\bar{X}$	
I	05-24	0.84	0.81	-0.03	-0.03	0.81	0.96	16.70
	05-26	1.09	1.07	-0.03	-0.02	1.07	0.98	21.90
	05-28	1.75	1.40	-0.20	-0.11	1.55	0.88	35.05
	05-30	2.11	1.54	-0.27	-0.13	1.84	0.87	42.15
	06-01	2.35	1.90	-0.19	-0.08	2.16	0.92	47.00
	06-03	2.51	1.98	-0.21	-0.08	2.30	0.92	66.00
	06-05	4.31	1.16	-0.72	-0.71	3.41	0.83	82.55
	06-10							100.00
II	05-24	0.60	0.63	0.04	0.07	0.64	1.07	12.00
	05-26	0.97	0.98	0.01	0.01	0.98	1.01	19.30
	05-28	1.46	1.30	-0.11	-0.08	1.35	0.92	29.25
	05-30	1.79	1.54	-0.14	-0.08	1.64	0.92	35.75
	06-01	2.11	1.75	-0.17	-0.08	1.94	0.92	42.20
	06-03	2.51	1.98	-0.21	-0.08	2.30	0.92	50.15
	06-05	3.90	1.21	-0.69	-0.18	3.21	0.82	78.00
	06-10							100.00

Data in Table 3 showed that the dispersion parameters obtained on May 24 and 26 from plot II had the characteristics of random distribution ( $I = 0$ ,  $Ca = 0$  and  $\overset{*}{M}/\bar{X} = 1$ ), while all the others followed those of uniform distribution with  $I < Ca0$ ,  $< 0$  [sic,  $I < 0$ ,  $Ca < 0$ ] and  $\overset{*}{M}/\bar{X} < 1$ . This indicated that the spatial distribution pattern of soybean aphid had its own characteristics: That is, in the beginning of aphid infestation with low percentage of infested plants, the spatial distribution of infested plants partly followed the uniform distribution and partly followed random distribution. Whether this was related to the environmental situation when the winged

aphids migrated from their overwintering hosts to soybean field needs to be clarified by further research work. These characteristics of spatial distribution at the early infestation stage changed and switched to uniform distribution as the infestation rate increased.

Furthermore, the regression equation between the average crowdedness ( $\bar{M}^*$ ) and mean ( $\bar{X}$ ) was also applied to examine the pattern of spatial distribution. The result was:

$$\bar{M}^* = 0.2126 + 0.7903\bar{X} \quad (5 \text{ plants per quadrat}) \quad r = 0.997$$

This also indicated that the spatial distribution of aphid infested plants was a uniform distribution because the equation above has parameter values of  $\alpha > 0$  and  $\beta < 1$ .

## 2.2 Sampling techniques

**2.2.1 Comparison of the sampling techniques.** Because the spatial distribution of aphid infested plants was a uniform distribution, any sampling technique could be used to investigate the rate of aphid infested plants as long as the sampling numbers reached the required level. Thus, we focused our sampling technique study on the aphid density investigation.

The statistical analysis was based on 8 sets of data from test plot I. Each set of data was considered a population. We recorded the population aphid numbers and calculated the aphid mean per plant in the population. Then four sampling techniques -- diagonal line, parallel line, "Z" form, and chessboard method -- were used to sample from the marked plants on the plotting paper. Each method sampled 12 spots with 20 plants each and 240 plants in total. The aphid numbers in each quadrat and the entire sample were recorded and used to calculate the aphid mean per plant in the sample. Then the aphid means of the populations were used as a control, and the deviations between population and sample means and error rates were calculated (Table 4). In addition, the sample means of the four sampling techniques were paired with their population means and tested for significance of difference (t-test). The results were: the diagonal sampling method had the highest error rate, while the error rates of all the other three methods were close and very small. The t-test results also showed that only the sample means from diagonal sampling were significantly different from the population means. There were no significant differences between sample means and population means by the other three sampling methods. Therefore, all the tested sampling methods except the diagonal line method can be used in aphid density investigation.

Table 4. Means of different sampling techniques and their error rates

Item	Sampling method	Examined date (M/D) and values (aphid mean/plant)								Total Average	
		5/23	5/24	5/26	5/28	5/30	6/01	6/03	6/05		
Mean $\bar{X}$	Population(ck)	0.878	0.845	1.482	4.009	6.405	7.043	14.77	28.97	64.41	8.051
	Diagonal line	0.875	0.437	0.829	2.650	5.675	5.570	12.75	24.76	54.55	6.820
	Parallel line	0.912	0.566	1.112	3.679	6.258	7.120	15.83	30.52	66.00	8.250
	"Z" form	0.768	0.795	1.558	4.663	7.266	7.150	13.46	36.75	72.38	9.048
	Chessboard	0.716	0.712	1.358	3.637	6.179	6.725	13.60	26.77	59.71	7.463
Error rate	Diagonal line	0.003	0.483	0.441	0.339	0.114	0.067	0.137	0.145	1.729	0.216
	Parallel line	0.039	0.330	0.249	0.082	0.023	0.011	0.072	0.053	0.860	0.108
	"Z" form	0.125	0.059	0.051	0.156	0.134	0.015	0.089	0.269	0.899	0.112
	Chessboard	0.185	0.157	0.084	0.093	0.035	0.045	0.079	0.076	0.754	0.094

**2.2.2 Theoretical sampling numbers.** The formula for theoretical sampling numbers with parameters of average crowdedness ( $\bar{M}^*$ ) and mean ( $\bar{X}$ ) proposed by Iwao (1971) is:

$$n = \frac{t^2}{D^2} \left( \frac{\alpha + 1}{\bar{X}} + \beta - 1 \right)$$

Where  $t$  is the expected probability,  $D$  is permissible error, and  $\bar{X}$  is the mean of aphid density.

If 5 plants is a quadrat, then  $\alpha = 97.44$ ,  $\beta = 1.36$ ; If we set  $t = 1$  and  $D = 0.2$ , the theoretical sampling numbers ( $n$ ) for soybean aphid density investigation would be:

$$n = \frac{1^2}{0.2^2} \left( \frac{97.44 + 1}{\bar{X}} + 1.36 - 1 \right) = 2461 / \bar{X} + 9$$

Thus, we can calculate the theoretical sampling numbers for soybean aphid investigation at different density levels (Table 5). Data in Table 5 show that the sampling number decreases as the mean of soybean aphid density increases.

Table 5. Theoretical sampling numbers for soybean aphid density investigation

$\bar{X}$ (aphid # /5 plants)	5	10	50	100	500	1000	10000
n (sampling #)	501.2	255.1	58.2	33.6	13.9	11.5	9.2

As for the aphid infested plant investigation, if five plants is a quadrat, then  $\alpha = 0.2126$ ,  $\beta = 0.7903$ ; if we set  $t = 2$  and  $D = 0.2$ , the theoretical sampling numbers ( $n$ ) for aphid infested plant investigation would be:

$$n = \frac{2^2}{0.2^2} \left( \frac{0.2126 + 1}{\bar{X}} + 0.7903 - 1 \right) = 121.26 / \bar{X} - 20.97$$

The theoretical sampling numbers for aphid infested plant rate investigation calculated from the above formula are shown in Table 6.

Table 6. Theoretical sampling numbers for aphid infestation rate investigation

$\bar{X}$ (aphid # /5 plants)	0.5	1	2	3	4
n (sampling #)	221.5	100.3	39.7	19.5	9.3

Data in Table 6 indicate that 40 quadrats (each has 5 plants) are required when the aphid infestation rate is 40%; whereas, 10 quadrats are enough when the aphid infestation rate reaches 80%.

2.2.3 *Sequential sampling.* Based on the linear regression between average crowdedness ( $M^*$ ) and mean ( $\bar{X}$ ), the sequential sampling equation Iwao proposed in 1975 was:

$$T_o'(N) = Nm_o + t\sqrt{N[(\alpha + 1)m_o + (\beta - 1)m_o^2]}$$

$$T_o''(N) = Nm_o - t\sqrt{N[(\alpha + 1)m_o + (\beta - 1)m_o^2]}$$

According to the formulae above, sequential sampling for both aphid density investigation and aphid infested plant rate investigation is as follows:

For sequential sampling of aphid density,  $\alpha = 97.44$ ,  $\beta = 1.36$  when five plants are a quadrat; if we set  $t = 1$  and  $m_o = 500$  aphid/5 plants = 100 aphids/plant (management guideline), then,  $T_o(N) = 500N \pm 373.12\sqrt{N}$

If we replace the sampling number  $N$  in the above formula with different values, we can obtain  $To'(N)$ —upper limit and  $To''(N)$ —lower limit (Table 7 and Figure 1).

Table 7. Sequential sampling values for soybean aphid density

N	$To'(N)$	$To''(N)$
10	6179.9	3820.1
15	8945.1	6054.9
20	11668.6	8331.4
25	14365.6	10634.4
30	17043.7	12956.3
35	19707.4	15292.6
40	22359.8	17640.2

Note:  $m_0 = 100$  aphids/plant

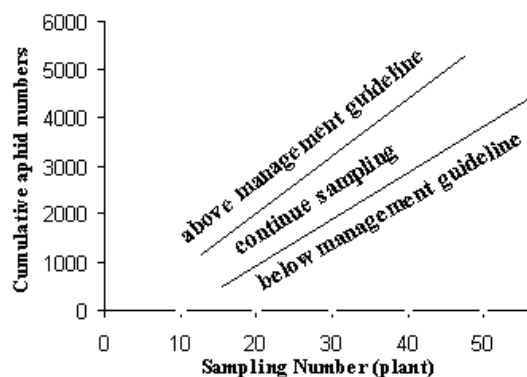


Figure 1. Sequential sampling for aphid density

For the sequential sampling of aphid infested plant rate, we have parameter values of  $\alpha = 0.2126$  and  $\beta = 0.7903$  when five plants are considered a quadrat. If we set  $t = 1$  and  $m_0 = 70\%$  (management guideline), then,  $T_o(N) = 3.5N \pm 1.29\sqrt{N}$ .

When we substitute  $N$  with different sampling values in the above formula, we can obtain  $To'(N)$ —upper limit and  $To''(N)$ —lower limit (Table 8 and Figure 2).

Table 8. Sequential sampling values for aphid infested plant rate

N	$To'(N)$	$To''(N)$
10	39.1	30.9
20	75.8	64.2
30	112.1	97.9
40	148.2	131.8
50	184.1	165.9

Note:  $m_0 = 100$  aphids/plant

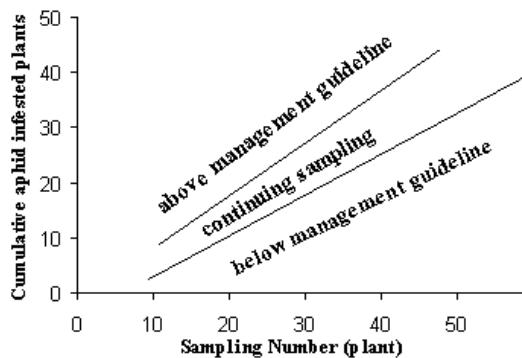


Figure 2. Sequential sampling for aphid infested plant rate

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